# RANKING OF THE BARRIERS TO IMPLEMENTING INDUSTRY 4.0 IN MANUFACTURING INDUSTRY

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In partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

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# CANDIDATE'S DECLARATION

I, ROSHAN KUMAR, hereby certify that the work which is being presented in the thesis entitled "RANKING OF THE BARRIERS TO IMPLEMENTING INDUSTRY 4.0 IN MANUFACTURING INDUSTRY" being submitted by me is an authentic record of my work carried out under the supervision of Dr. Pravin Kumar, Associate Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

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# CERTIFICATE

I hereby certify that the Project Dissertation titled "**RANKING OF THE BARRIERS TO IMPLEMENTING INDUSTRY 4.0 IN MANUFACTURING INDUSTRY**" which is submitted by **ROSHAN KUMAR**, **2K18/PIE/502**, Department of Mechanical, Production & Industrial and Automobile Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **(Dr. PRAVIN KUMAR)**

Date: 21/09/2021 SUPERVISOR

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## ABSTRACT

Industry 4.0 leads to the fourth revolution of the industry with digitalization of the industrial processes. It has been observed that the manufacturing industry is facing many barriers. These barriers are related to government policy, management initiatives, human resources, infrastructure and financial resources, and technology.  To prioritize or making the important ranking of the barriers Best-Worst Method is applied. Best-Worst Method is the extension of the Analytic Hierarchy Process. It is found that lack of Infrastructure, Lack of financial resources, lack of government initiatives, high complexity, and cyber security and data ownership issues are five important barriers in the order of decreasing importance. This study may help the manager to remove the barriers in the implementation of Industry 4.0.

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## Chapter 1

# Introduction

The enactment of industry 4.0 has emerged as an effective and influential method that brings a technological improvement in the development of production, research, and management. This is because of the fact that there is a digital inclusion of modern practices of technical and digital facilities into the manufacturing processes and the related services. There has been constant change in the process of industrialization wherein industry 1.0, there was a significant dependence on steam power, while in industry 2.0, the transition occurred to an energy-driven assembly line. The progress stopped here and shifted to the programmable logic control systems where the drives steadily become automatic in nature. Today is the era of agile manufacturing where digitalization and communication based technologies and techniques play a vital role (Oztemel et al., 2020).

Through automation and data interchange, Industry 4.0 technology has become a global inclination in the manufacturing industry. This fourth industrial revolution brings digitalization in manufacturing, in which all aspects of production are connected and computerized. The internet of things, robotic systems, additive 3D printing, and artificial intelligence are all part of Industry 4.0 which has the ability to create a "smart factory.” The technologies mentioned above achieve cyber-physical systems that integrate the physical world with the digital world by monitoring physical processes, making digital copies of the physical world, and making decentralized production systems, where people, machines, and resources communicate with one another (Rezqianita et al., 2020).

Industry 4.0 has posed various problems for emerging economies such as China, Brazil, and India and where low labour costs would not be advantageous. In today's era of globalization, where the availability of the internet and availability of 5G technology has emerged and is contributing to the advancement of the technology. This has resulted in the development of the world's industry in a thorough and uniform manner (Kumar et al., 2020).

The “Make in India” program launched by the Indian government to promote the manufacturing ecosystem brings a positive stance in the industrial sector. According to data provided by the Indian government, Gross Value Added in the manufacturing industry in India between 2012 and 2018 at a CAGR of 4.34 percent. Industry 4.0 is gradually being implemented through programmes such as smart cities and digital India. In the application of industry 4.0 technology, improved price, productivity, value, flexibility, employee satisfaction, etc. (Kamble et al., 2018).

### 1.1 Industry 4.0

In 2011, Hanover Fair put forward the idea of Industry 4.0 technology, and the German government took it as an initiative to improve and developed its manufacturing environment in 2013(Li, 2017). The salient features of Industry 4.0 are presented in Figure 1.1.

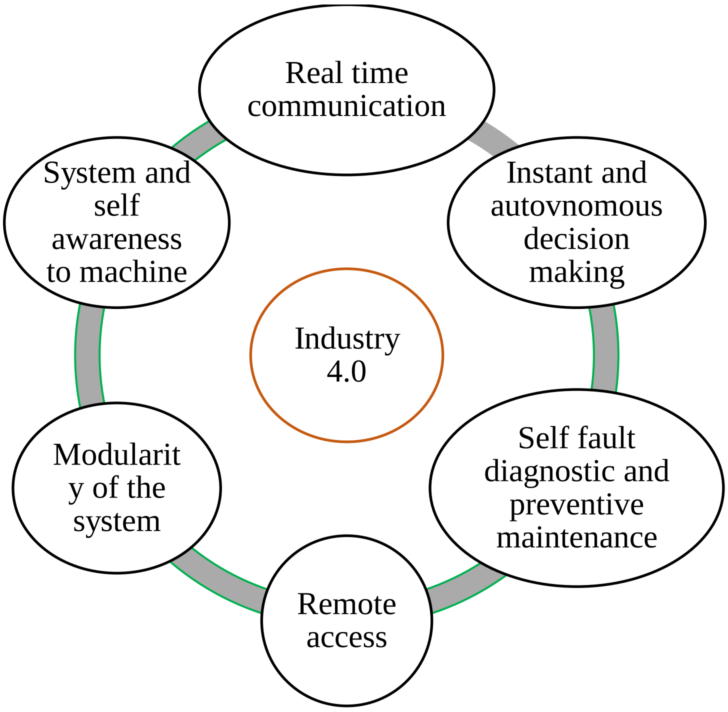


Figure 1.1: Salient features of Industry 4.0 (Sources: Kumar et al., 2020)

Industry 4.0 has developed as an essential technique that uses technological inclusion to overcome the limitations of industry 3.0 and boost the development of manufacturing and technical processes. With the increase in population, there is a need to multiply the goods and services, ensuring longer life with the adequate quantity and without compromising the quality. Due to the rapid influence of globalization, there is a need to develop a relationship between the man and the machine, thus making the Inclusion of Industry 4.0 more important in the present manufacturing scenario where there is a need for rapid development.

Artificial Intelligence, along with the internet of things, which is a subset of artificial intelligence (AI) is a critical player in building the unbreakable relationship between the workers and machines. It has to boost the development of industrial products catering to the need of man and environment and provided a cost effective solution and inclusiveness of Industry 4.0 (Laudante, 2017).

## 1.2 Industrial Growth

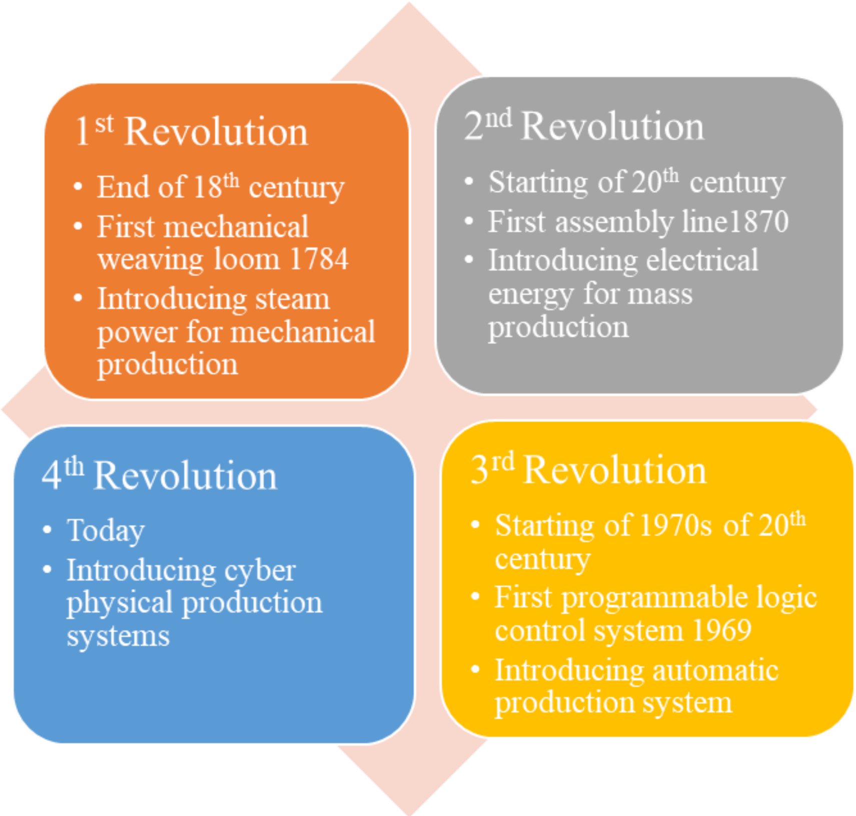


Figure 1.2: Industrial Revolution (Source: Horváth et al., 2019, Deloitte, 2014)

At the end of the 18th century, the world entered into the first industrial revolution. At that time, the manufacturing industry was labour centric, usually performed by individuals in an optimized frame of delivery by the utilization of steam-powered motors and water (Horváth et al., 2019) (Deloitte, 2014).

With the onset of the 20th century, the world entered into the second industrial revolution, introducing steel and electricity in factories. It increases the efficiency of the manufacturing industry and makes machinery more portable by introducing electricity. Throughout this period, the assembly line in mass production was presented to boost productivity (Horváth et al., 2019) (Deloitte, 2014).

At the starting of the 1970s, the world entered into the third industrial revolution. The third industrial revolution, often known as the "digital revolution," incorporates computer technology as well as electronic systems in manufacturing industries to put lesser accentuation on mechanical innovation but put emphasis on automation and digital technology (Horváth et al., 2019), (Deloitte, 2014).

Now the world entered into the fourth industrial revolution. Digital technology, which is inspired by industry 4.0 having a new level with the help of interconnectivity by the introduction of the cyber-physical systems, the internet of things (IoT), and admittance to ongoing information. All the different revolutions of Industrial Engineering are shown in Figure 1.2.

It offers a wider range and comprehensive strategy to the manufacturing industry, providing greater support and access between various departments, goods, people, partners, and vendors by connecting the real and digital worlds. It allows manufacturers to understand each and every feature of their operation and influence actual data to increase output, accelerate growth and streamline the process (Horváth et al., 2019), (Deloitte, 2014).

A new methodology for transforming machine-leading manufacturing to digital manufacturing was made possible by the application of industry 4.0

## 1.3 Essential elements of Industry 4.0

The essential elements of industry 4.0 are shown in Figure 1.3.

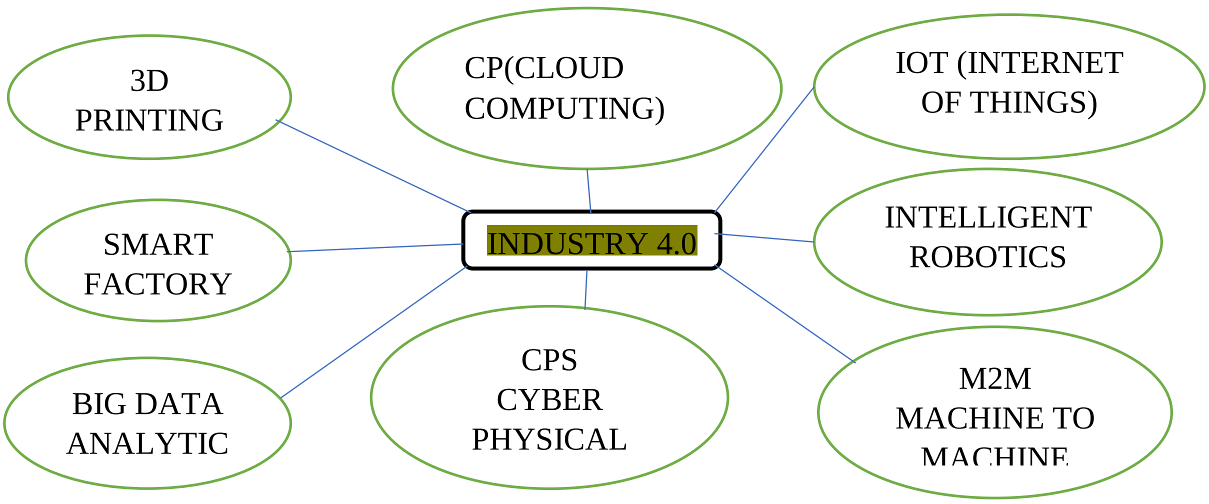


Figure 1.3: Essential elements of Industry 4.0

### 1.3.1. Cloud computing

Remote services, performance benchmarking applications, and colour management is the basic cloud application. Data management, equipment related to the manufacturing industry, and its functionality will remain migrates from customary methods to cloud based elucidations as technology improves. The cloud system helps to deliver more rapidly than standalone, is easy to bring up-to-date, and to have data performance models and other delivery options up to date. Cloud technology is the most basic internet storage solution, with the application of web-based apps that don't need any installation. Cloud computing is used for storing programs data and applications in a virtual server. It helps to reduce costs, simplifies infrastructure, expands work areas, protects data, and allows for instant access to information. Cloud computing is classified as private cloud, hybrid cloud, public cloud, and community cloud. The different features of cloud computing is summarized in Table 1.1.

As a result, cloud systems and data analysis might be inescapable parts of industry 4.0. The impact of the robot, which is cloud connected having highly significance in our everyday life. The transition to the Industry 4.0 will enhance manufacturing speed and quality, benefiting not only large firms but also small industries (Oztemel et al., 2020). Strengths of cloud computing are:

- Scalability
- Data accessibility
- Cost reduction
- Low maintenance

Weaknesses of Cloud computing are:

- Distance from the data source
- Network connection dependency
- 3rd party security

Table 1.1: Uses of Cloud computing in the Manufacturing Industry

| Sr. No | Features of Cloud Computing | Description |
|---|---|---|
| 1 | Flexibility | • Industrial activities vary as per the customer's request.<br>• Flexible storage and computing framework is required to guarantee ideal information collection, analytics, and operations.<br>• It also provides a centralized storage place for the multiple facilities you intend to digitize. |
| 2 | Data Security | • With digitization comes cybersecurity risks, which can result in outage and data theft.<br>• Integrates enterprise-grade security management |

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| | | solutions to protect data and minimize security threats. |
| 3 | Backup data and recovery | • Data gathering and management systems are nearly, but not entirely, flawless.<br>• With the right cloud platform, the machine data stays secure and backed up against complete data loss. |
| 4 | Automated Upgrades | • Upgrades and new features are included in the bundle.<br>• This includes new features, security certificates, and communication protocols that are included at no additional cost with every technological upgrade. |

**1.3.2 3D Printing**

To summarize, we are in the new era of a new industrial revolution, namely Industry 4.0. The 3D printers are poised to show a key part in the digital change of industry as their speed, dependability, safety, and quality increase, and their cost decreases. In place of the performance of 3D printers improves quickly, as costs fall, new opportunities will emerge, bringing it closer to mass manufacturing. The sources grow the variety of products that can be made and are expected to expand (Oztemel et al., 2020).

Individual spare parts may be produced using 3D printing, taking advantage of the shorter production lead-time and flexibility to prolong lifetime product and their components, resulting in significant environmental and social benefits (Zheng et al., 2020). The various parameters of 3D printing are mentioned in Table 1.2.

Table 1.2: The use of 3D printers that have significant parameters are as follow

| Sr, No | Parameters | Description |
|---|---|---|
| 1 | Printing speed | • Parts must be printed in minutes, not hours, to digitally change the manufacturing industry. |
| 2 | Quality | • Early 3D printers were not particularly precise, especially when producing complicated patterns. Nowadays, in the advancement of 3D software and technology used to remove this stumbling block. |

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|---|---|---|
| 3 | Safety | • 3D printers relied on high-temperature technology. Additionally, the printers were rather big. However, in the recent, it prominent manufacturers like as Stratasys have brought almost considerable modifications in how printers operate. |
| 4 | Environmental effect | • Environmentally aware producers may utilise earth friendly biodegradable material as a result of 3D printing, which reduces waste.<br>• This lowers the number of unsold goods. As a consequence, unused or discontinued items do not wind up in landfills. |
| 5 | High-quality Printing Material | • In the new revolutionary era of the manufacturing industry, 3D printers print everything either in metal or in food. The moderation of printing materials increases help industries to manufacture anything related to customer desire. |
| 6 | Software and 3D printing | • New software able to process this big data, and this big data directly sent to 3D printers when prototyping, the importance of 3D printers will only grow in the future. |
| 7 | Price | • Apart from concern about speed, the 3D printers having the higher installation cost become the biggest obstacle for mass scale digitalization.<br>• 3D printer prices are expected to continue to fall. As the cost of 3D printers decreases, more people will purchase them, benefiting everyone. |

### 1.3.3 Smart factories

When manufacturing is termed as the multi-staged process of generating a new manufactured good from raw materials, the subset does this through computer control and high degrees of flexibility. It seeks to use sophisticated manufacturing technologies and information to provide physical process flexibility (highly active and global market) (Oztemel et al.,2020).

Big data analytics, additive manufacturing, robotic system, the internet of things are all part of Industry 4.0 and its ability to create a smart factory. By observing all the physical processes, it helps to create digital copies of the physical world and creating decentralized production systems where machines, resources, and people communicate with one another;

these technologies enable cyber-physical systems that connect the physical with digital worlds (Rezqianita et al., 2020).

### 1.3.4 Big data analytics

In this manufacturing world, this environment, on a continual basis, generates big data. Digital operation and social media interaction is the key to generates data. Sensors, mobile devices, and systems transmit data. It pours at an alarming rate, volume, and vast form of sources. Information management skills and analytics capabilities are required to expand values from big data.

### 1.3.5 Internet of things

The Internet of Things (IoT) discusses about the interconnection of physical devices. In this field, buildings, cars, and other units are equipped with sensors, network connectivity, software, and electronics that help devices assemble and interchange data. It classified into four major layers that are the network layer, support layer, application layer, and perception layer. Because IoT-enabled manufacturing systems are linked to web-based platforms, this results in more productive and hopeful working environments. This forces key standards to show a larger role towards the development of optimizations and strategies. Manufacturing industrial systems based on the Internet of Things to make decisions that are quicker, optimistic, and more timely than others. This, on the other hand, is dependent on the system's design and related intelligence. Human intelligence and knowledge integrate the internet of things and industry 4.0 in effective and the most efficient ways (Oztemel et al.,2020).

### 1.3.6 Intelligent robotics

Technology continues to surprise us with new goods and systems. Holographic television, the connectivity of hundreds of electronic gadgets, and flying automobiles implanted into the human body will no longer be a pipe dream in the near future. Humanoid robots will be a part of everyday life in the not-too-distant future. One of the difficulties they will face is communication, which will be addressed through leisure activities. For the use of humanoid robots in industries, this is an unavoidable development. Robots can now play games, move across any terrain, and do extremely difficult tasks. Techniques that allow robots to manage their surroundings have recently been developed as a result of recent advances. Artificial intelligence will aid in the advancement of robot teams cooperating and collaborating to complete tasks that have been defined for a specific reason. Some robotics research might be useful in aiding efficient digital transformation (Oztemel et al. 2020).

It is self-evident that robotics will play a significant role in Industry 4.0. Robots are capable of doing difficult or large tasks. They are also capable of working in hazardous or unpleasant situations. They serve as a guideline for everyday procedures. Despite the high expenses of building and upkeep, robots appear to be the primary source of work. They can close social exploits by engaging with individuals in a reasonable manner.

### 1.3.7 Machine to machine (M2M)

Machine-to-machine (M2M) communication refers to direct communication between devices via any channel, whether wired or wireless. Industrial instrumentation, for example, can utilise machine to machine communication to send data from a sensor or meter to application software that can use it. A distant network of devices relayed information back to a central hub for processing, after which it was redirected into a system resembling a personal computer. M2M (machine-to-machine) is a technology that enables companies to invest in wireless communication between data centers and machines (Oztemel et al.,2020). When a criminal breaks into a residence, a GSM connection may send SMS to mobile phones. Making communication technology, whether cable or wireless, as simple and inexpensive to deploy as feasible has paved the way for life-improvement advances. M2M is also seen as an important component of Industry 4.0.

### 1.3.8 Cyber-Physical Systems (CPS)

Computing and physical processes are important components of Industry 4.0 implementations, and Cyber-Physical Systems (CPS) combine both. They incorporate imaging and control capabilities into the systems that are relevant. The ability to respond to any feedback generated is a key feature of these systems. They enable real-time control and verification of process feedbacks in order to produce desired results. A virtual environment is generated by computer simulation of things and behaviors in the real world and a network of objects and systems interacting through the internet with a specified address (Oztemel et al.,2020).

### 1.4 Manufacturing Processes

The major applications of Industry 4.0 in manufacturing industry are summarized in Table 1.3.

Table 1.3: Summary of application of industry 4.0 in the manufacturing process

| Process | | Description |
|---|---|---|
| New product development | Zheng, T. et al. (2020), Stentoft et al. (2019) | Design, testing, and prototyping of a product before its production and marketing. |
| Supply chain | Kumar et al. (2020), Deloitte (2014), Zheng, T. et al. (2020) | The decision-making process is connected to the strategic decisions made at the managerial level in terms of network design (number of levels, supplier selection, manufacture or purchase strategy) and factory architecture, which includes material flow management and asset location. |
| Integrated supply chain planning | Zheng, T. et al. (2020) | Demand forecasting and planning, distribution sourcing, material positioning at various stages of the supply chain (inventory planning), and manufacturing are the main areas of focus (master production scheduling). |
| Internal logistics | Zheng, T. et al. (2020) | Storage, internal product handling, and production enslavement are all part of the factory's operational logistics. |
| Production scheduling and control | Zheng, T. et al. (2020) | Factory planning such as managing machine load and batch division as well as production observing and control are also part of this process. |
| Energy management | Zheng, T. et al. (2020), Horváth et al. (2019) | All resources used in production and for the factory's overall operation are monitored and controlled. |
| Quality management | Zheng, T. et al. (2020) | Controlling production in terms of both goods (e.g., product faults) and procedures in the factory (e.g., production parameters). |
| Maintenance management | Zheng, T. et al. (2020), Horváth et al. (2019) | The asset management department (including a breakdown and preventive maintenance) manages asset planning and maintenance. |

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|---|---|---|
| Customer relationship | Zheng, T. et al. (2020), KIEL et al. (2017) | All actions involving consumer engagement are included in the process. It also consists of the management, service delivery (customised), and development of physical products. |
| After-sales management | Zheng, T. et al. (2020) | After-sales process management, which includes operations such as technical support, product maintenance, and spare parts. At the conclusion of a product's lifespan, management, recovery, and disposal are necessary. |

### 1.4.1 New product development

In certain situations, this process might entail modifying a current product in order to accomplish particular improvements and meet new consumer demands. Several contributions to the literature have been made about the use of digital technology to aid in this process (Zheng, T. et al., 2020). Table 1.4 shows the role of Industry 4.0 technologies in New Product Development.

Table 1.4: Effect of Industry 4.0 technologies on new product development.

| Sr. No | Technologies | References | Application |
|---|---|---|---|
| 1 | Cyber-physical systems | Miranda et al. (2019) | • Smart product development |
| 2 | Internet of things | Bressanelli et al. (2018), Tao et al. (2019) | • Data collection for product design improvements |
| 3 | Big data and analytics | Dalenogareet al. (2018), Tao et al. (2019) | • Data processing and analysis for better product design |
| 4 | Cloud technology | Rao et al. (2018) | • Design that is distributed and collaborative |
| 5 | Artificial intelligence | Ang et al. (2017) | • Data processing and analysis for product design improvements |
| 6 | Blockchain | | • Virtual prototyping |

| | | | |
|---|---|---|---|
| | Simulation and modelling | Miranda et al. (2019), Qi and Tao (2018) | • Technical product assessment<br>• Digital product representation |
| 7 | Visualization technology Automation and industrial robot | Zhong et al. (2017) | • Augmented design |
| 8 | Additive manufacturing | Ang et al. (2017) Chong et al. (2018) | • Digital complex design<br>• Rapid prototyping |

### 1.4.2 Supply chain

The supply chain leads to the strategy for the location of various facilities, e.g., plants, warehouses, etc., including the number of levels. The next step is to think about the industrial layout, which is significant for process efficiency. The tactical decisions taken for better supply chain configuration also include plant layout of production system design. In this situation, big data analytics may be quite useful in bringing data from many platforms together (Zheng et al., 2020). The usage of Industry 4.0 technologies in supply chain management are summarized in Table 1.5.

Table 1.5: Usage of Industry 4.0 technologies in the supply chain.

| Sr. No | Technologies | Source | Application |
|---|---|---|---|
| 1 | Cyber-physical system | Durão et al. (2017) | • Distributed production of spare parts |
| 2 | Internet of things | Srai et al. (2019) | • Smooth purchasing and supply management |
| 3 | Big data and analytics | Kumar et al. (2018) | • Plant layout design and assessment |
| 4 | Artificial intelligence | Kumar et al. (2018), Diez-Olivan et al. (2019), Ghadimi et al. (2019) | • Factory layout design and evaluation<br>• Smart purchasing and supply management |

| | | | |
|---|---|---|---|
| 6 | Additive manufacturing | Zanoni et al. (2019) | • Distributed production of spare parts |

The term "integrated supply chain planning" refers to the organisation and administration of many components of the supply chain, including commodities, suppliers, inventories, and demand forecasts. The use of digital technology to help manage all of these elements leads to better synchronization across the supply chain.

Usually, IoT and Big Data Analytics allow businesses to predict and influence future consumer wants, resulting in increased efficiency in end-product distribution. Inbound as well as outgoing flows, on the other hand, can be tracked more precisely using IoT and BDA technology, allowing for automatic and more exact demand planning and forecasting.

### 1.4.3 Internal logistics

The handling and storage of items within the factory are dealt with by internal logistics. The transportation of materials, as well as the support activities of warehousing, stock control, material handling, and production feeding, are all included in this process. Internal logistics personnel, in particular, are responsible for guaranteeing a secure supply of goods, thus cost and time efficiency are critical in this business. Many suggestions for enhancing internal logistics may be found in the 4.0 enabling technologies.

The basic tools of industry 4.0, such as the internet of things, Industrial Robots, artificial intelligence, Simulation and Modeling, and Visualization Technology and Automation, all have applications in Internal Logistics operations, as illustrated in Table 1.6. There have been no suitable applications discovered for the other technologies investigated (Zheng et al., 2020).

Table 1.6: Applications of Industry 4.0 technologies on internal logistics.

| Sr. No | Technologies | | Application |
|---|---|---|---|
| 1 | Internet of things | Zhang et al. (2019), Novais et al. (2019) | • Material identification and tracking<br>• Internal transportation, line feeding, and material handling automation |
| 2 | Artificial intelligence | Lee et al. (2018) | • Order picking management |

| | | | |
|---|---|---|---|
| 3 | Simulation andmodelling | Hofmann et al. (2017) | • Material flow simulation in factories and warehouses |
| 4 | Automation and industrial robots | Novais et al. (2019), Tang et al. (2019) | • Internal shipping, material management, automation, and line feeding |

### 1.4.4 Production scheduling and control

The scientific literature has given the most attention to production scheduling and control. Apart from blockchain, all other industry 4.0 enabler technologies have been discovered to have various uses in this process. Cyber physical system has a significant influence on the manufacturing system. The tool focuses on the supervision of cyber-physical production systems, the virtualization of manufacturing resources, and scheduling (Zheng et al., 2020).

### 1.4.5 Energy Management

In the case of growing attention to emissions and sustainability, energy management has become an incredibly significant problem. Energy management plays a vital role to improve emissions. There has been a rise in publications detailing uses of industry 4.0 enabling technologies in support of energy management in recent years, due in part to a rising focus on the circular economy, despite the fact that the subject is still largely unexplored (Zheng et al., 2020).

### 1.4.6 Quality Management

The use of an IoT platform can improve the separation of clinically defected data and help avoid quality defects and save materials. As a result, the major use of the Internet of Things in quality management is the identification of quality defects in factory-made items. Moreover, Big Data Analytics allows for precisely analyzing the data related to the manufacturing process and making it simple to identify minor variations in the quality of any product (Zheng et al., 2020).

### 1.4.7 Maintenance Management

As we know that maintenance is one of the essential aspects of the manufacturing industry. Maintenance management application helps reduce resource consumption and manufacturing efficiency with slight deviation (Zheng et al., 2020).

### 1.4.8 Customer relationship Management (CRM)

All the processes, which include assurance as per customer demands based upon personal experience, are studied under CRM. for example, a manufacturing company's distinctive elements are advanced and customised services for any physical product and its design and deliverance. As a result, the producer gains a significant competitive edge and increases consumer loyalty. This process is referred to as "servitization" in the literature, and it can be aided by the incorporation of digital technology. (Zheng et al., 2020).

## 1.5 Conclusion

In this chapter, Industry 4.0 is introduced with the application in different areas of manufacturing as well as supply chain management. Various technologies involved in Industry 4.0 are introduced with their significance in supply chain management.

**Chapter 2**

# Literature Review

Industry 4.0 has a significant impact on the today's economy, starting from the food and packaging sector to the manufacturing sector. The use of industry 4.0 is being considered at all levels, from primary to secondary and even tertiary. Many researchers concentrated their study on the field of mining and applied the concept of Industry 4.0 in the mining sector (Preston & Herron, 2016) (Preston et al., 2016), (Singh et al., 2020).

The world has seen the greatest transformation in industrialization in the era of Industry 1.0. There was a time of weaving loom, and now in industry 4.0, there is a concept of cyber Physical production system. Oztemel et al. (2020 gave an account of the application of industry 4.0 and highlighted its application in the present era, and gave significant conclusions.

Li et al. (2018) compared the development of industry in china with the concept of industry 4.0 and highlighted the significant conclusions in the field of technological forecasting and their impact on the social environment and on the people. Laudante et al. (2017) studied industry 4.0 about the ergonomics analysis in the manufacturing system and suggested the needful changes with the help of the application of industry 4.0. With the emergence of modern needs and cyber requirement there is a need to shift the manual based work environment to the internet and robot-based environment for which there is a high requirement for the digital transformation. But these transformations are not simple to adopt as they possess challenges that are not easy to cater upon.

Deloitte (2014) highlighted the significant challenges which are present in the industry 4.0 phase and came out with the solution to overcome them. Zeng et al. (2021) gave the literature review for the application of industry 4.0 in the field of the manufacturing sector, and methods for its successful operations were also highlighted in the study. In continuing the digital transformation, there is a need to study the product and the services evolved from industry 4.0. Miranda et al. (2019) studied intelligent sensing and sustainable product.

### 2.1 Barriers in implementation of Industry 4.0

The researcher gave a valuable conclusion and put forward their point on industry 4.0. Bresasnelli et al. (2018) applied the concept of Industry 4.0 to overcome the challenges in the PSS Business model. The researcher emphasized the role of technologies to overcome

Circular Economy challenges. Talking about digital technologies (Tao et al., 2019) gave the framework for smart manufacturing based on information technology.

Dalenogare et al. (2018) studied the contribution of industry 4.0 and to enhance the performance of the industry, and the researchers gave valuable suggestions. Rao et al. (2018) studied the impact of 5G technologies on industry 4.0 and its importance in the successful functioning of industry 4.0. Ang et al. (2017) studied the implementation of industry 4.0 concepts in the ship manufacturing industry. The researchers gave the valuable input required for the smart manufacturing of the ship building conforming to industry 4.0 standards. Qi et al. (2018) compaired the concept of industry 4.0 with the concept of big data in the field of smart manufacturing and came out with influential conclusions. Zhong et al. (2017) Studied industry 4.0 and connected it with respect to smart manufacturing. Chong et al. (2018) studied the hybrid manufacturing process based on digital technology and related the concept of industry 4.0 with it and gave valuable conclusions.

Durão et al. (2017) studied additive manufacturing in context with the distributed production of spare parts. Srai et al. (2019) worked on the concept of digitalization in the field of supply management and gave valuable conclusions in the area of Industry 4.0. Kumar et al. (2019) suggested the clean and effective approach in industry 4.0 application using the Big data approach. Diez- Olivan et al.(2019) suggested the fusion of machine learning with data fusion for overcoming the barriers in industry 4.0. Ghadimi et al. (2019) suggested the use of multi-agent technology in improving the application of industry 4.0 in the supply chains. The researchers highlighted the important point in an intelligent, sustainable supplier selection system. Zanoni et al. (2019) studied the supply chains in additive manufacturing.

Ivanov et al. (2019) studied the impact of digital technology in industry 4.0 and suggested the process of inclusion of digital systems in the improvement of supply chain management and industry 4.0 implementations. Zhang et al. (2019) suggested an IOT based mechanism for lean manufacturing system. Novais et al. (2019) gave a systematic literature review on supply chain flexibility and mass personalization. Lee et al. (2018) worked on the designing of IoT based smart warehouse system for the convenient logistic. Hofmann et al. (2017) studied the concept of industry 4.0 and its application in future logistics. On similar grounds (Tang et al., 2019), relate industry 4.0 with the logistic-based problems. Many authors have already worked on the barriers in implementation of Industry 4.0 in manufacturing and other industries as shown in Table 2.1 and Table 2.2.

Table 2.1: References associated with the selection of barriers to implementing industry 4.0

| Name of Researcher | Area of research | Methodology | Barriers |
|---|---|---|---|
| Kumar and Singh. (2021) | Analyze the impact of the barrier on the supply chain of food items in the COVID 19 pandemic (AFSC) | • Best-Worst Method (BWM).<br>• Quality Function Deployment (QFD). | From the study, the following barriers were identified:<br>• Increase in the cost related to manufacturing and supply of the products.<br>• International Trade is not trustworthy,<br>• Due to large quantity the deterioration in food nature.<br>• Proper Response is minimized.<br>• The resources are difficult to access, and their availability is a challenge.<br>• There is a problem with the transport of the resource.<br>• There is a problem in Imports of the resources and law abiding them.<br>• There is the problem of the allocation of resources.<br>• There is a problem of a factor of economy, and there should be an adequate supply of money and resources.<br>• Variation in the Price values.<br>• Consumable products must be kept safe and proper value must be taken.<br>• Unavailability of the Workers,<br>• The demand and supply behaviour of the products.<br>• Unavailability of food security<br>• Supply of high content food to workers. |
| Kumar et al. (2020) | Examine these barriers to make a supply chain more resilient. | • Analytic Hierarchy Process (AHP)<br>• Elimination and Choice Expressing Reality (ELECTRE) | • lack of waste management<br>• Use of materials as energy<br>• Poor resource/ infrastructure quality<br>• Lack of awareness of Industry 4.0.<br>• Lack of Govt. support, Employees<br>• Resistance to change<br>• Insufficient market demand<br>• Lack of management support, |

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| | | | • Short term goals, |
| Raj et al. (2020) | This is one of the first studies to look at how Industry 4.0 is being implemented. | Grey Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach. | • Difference in economic benefit.<br>• Limitations in value-chain integration.<br>• Challenges breaches in security.<br>• Irregularities in existing jobs.<br>• Infrastructure Shortage.<br>• Digital skills Shortage.<br>• Implementation of quality data.<br>• Internal digital culture and training.<br>• Ineffective change management.<br>• Scarcity of Resources. |
| Kumar et al. (2020) | Implementation of Industry 4.0. | principal component analysis (PCA), fuzzy analytical hierarchical process (fuzzy AHP), and K-means clustering. | • IT Infrastructure<br>• Matured data analytic techniques, Missing standards<br>• Data insecurity<br>• Very high complexity<br>• Poor compatibility of current solutions/ devices or retrofitting<br>• Huge investment<br>• Missing partners and funding support<br>• Management support<br>• Missing government support<br>• The unwarranted strain on the workforce<br>• Lack of regulatory mechanism |
| Rezqianita et al. (2020) | This research aims to determine the drivers and barriers to Industry 4.0 adoption in Indonesian manufacturing. using literature review that and have been validated through expert interviews. | The gathered drivers and obstacles were evaluated by interviewing experts and filling out a questionnaire. Experts ranked the list of drivers and obstacles as "valid" or "invalid" based on their expertise and experience. | • Lack of knowledge<br>• Inherent habits<br>• Strategy making difficulties<br>• Limited knowledge management<br>• Specific lighthouse<br>• Lack of Infrastructure<br>• Lack of competence from leaders, limited skilled leaders<br>• Lack of competence from the workforce<br>• Limited skilled workforce<br>• Lack of ability to identify opportunities<br>• Lack of commitment<br>• Lack of external experts<br>• Training time<br>• Policy about the ecosystem<br>• Policy about data security<br>• Lack of government's |

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| | | | Infrastructure<br>• Lack of incentives<br>• Lack of standards<br>• Cyber security<br>• Storage capacity. |
| Chauhan et al. (2020) | The current study examines how intrinsic and extrinsic barriers to digitalization influence industries' adoption of Industry 4.0. | Improvising the implementation of the fourth industrial revolution. | • Challenges at the elementary level,<br>• top management does not readily involve,<br>• Inadaptability of new technology.<br>• Improper digitalization.<br>• Inadaptability of the employee for advancement in technology.<br>• Data Incompetency,<br>• Improper Tools for Data Interaction<br>• Improper Cost Competency tool. |
| Ozkan-Ozen et al. (2020) | Industry 3.5 and 4..0 | Fuzzy Analytical Network Process | • Inadequate Information for Industry 4.0,<br>• Improper standards,<br>• Required continued education and training of employees,<br>• Required high investments,<br>• Data Sensitivity<br>• Data inadequately<br>• Data Management<br>• lack of management support for Industry 4.0 transformation,<br>• Inadequate environment for digitalization.<br>• Inadequate environment for communication<br>• Unsupportive legal support System. |
| Stentoft et al. (2020) | To look at the drivers and challenges to Industry 4.0 preparedness. | A mixed-method approach. | • Lack of standards,<br>• Few human resources (manpower),<br>• Absence of cyber security<br>• Inadequate of qualified workers<br>• Lack of employee readiness<br>• Improper Technology<br>• Improper Digitalization |
| Horváth et al. (2019) | To learn how senior executives perceive the idea of Industry 4.0. | With the application of the grounded theory approach and interviews. | • Lack of knowledge<br>• Inherent habits<br>• Strategy making difficulties<br>• Limited knowledge management Specific lighthouse<br>• Lack of Infrastructure |

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| | | | • Lack of competence from leaders Limited skilled leaders<br>• Lack of competence from the workforce<br>• Limited skilled workforce<br>• Lack of ability to identify opportunities<br>• Lack of commitment<br>• Lack of external experts<br>• Training time<br>• Policy about the ecosystem<br>• Policy about data security<br>• Lack of government's Infrastructure<br>• Lack of incentives<br>• Lack of standards<br>• Cyber security<br>• Storage capacity. |
| Stentoft et al. (2019) | questionnaire on the implementation of the fourth industrial revolution, Industrialization in 308 Industry. | Questionnaire-survey | • Challenges at the elementary level<br>• top management do not readily involve<br>• Inadaptability of new technology.<br>• Improper digitalization.<br>• Inadaptability of Employee for advancement in technology.<br>• Data Incompetency,<br>• Improper Tools for Data Interaction |
| Müller (2019) | Fears about employees being replaced by machines, particularly in low-skilled professions or repetitive work. Moreover, there is apprehension about new technology, as well as a limitation of staff capabilities. | Case study | • Inadequate Information for Industry 4.0<br>• Improper standards<br>• Required continued education and training of employees<br>• Required high investments<br>• Data Sensitivity<br>• Data inadequately<br>• Data Management<br>• lack of management support for Industry 4.0 transformation<br>• Inadequate environment for digitalization.<br>• Inadequate environment for communication<br>• Unsupportive legal support System. |
| Türkeș et al. (2019) | The main goal of this study is to find out what | Question-Answer Based approach. | • Technical Hindrance of Implementation of the fourth industrial revolution |

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|---|---|---|---|
| | SME managers in Romania. | | • Unavailability of Standards<br>• Data Insensitivity<br>• Unavailability of proper techniques<br>• Unavailability of Human Resources,<br>• education and Training of Workers. |
| Kamble et al. (2018) | Challenges for the implementation of industry 4.0 | ISM and fuzzy MICMAC | • Lack of knowledge<br>• Inherent habits<br>• Strategy making difficulties<br>• Limited knowledge management<br>• Specific lighthouse<br>• Lack of Infrastructure<br>• Lack of competence from leaders<br>• Limited skilled leaders<br>• Lack of competence from the workforce<br>• Limited skilled workforce<br>• Lack of ability to identify opportunities<br>• Lack of commitment<br>• Lack of external experts<br>• Training time<br>• Policy about the ecosystem<br>• Policy about data security<br>• Lack of government's Infrastructure<br>• Lack of incentives<br>• Lack of standards<br>• Cyber security<br>• Storage capacity |
| Orzes et al. (2018) | The purpose of implementation of the fourth generation of industrialization. | Focus on group methodology. | From the study, the following barriers were identified:<br>• Increase in the cost related to manufacturing and supply of the products.<br>• International Trade is not trustworthy,<br>• Due to large quantity the deterioration in food nature.<br>• Proper Response is minimized.<br>• The resources are difficult to access, and their availability is a challenge.<br>• There is a problem with the transport of the resource.<br>• There is a problem in Imports of |

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| | | | the resources and law abiding them.<br>• There is the problem of the allocation of resources.<br>• There is a problem of a factor of economy, and there should be an adequate supply of money and resources.<br>• Variation in the Price values.<br>• Consumable products must be kept safe and proper value must be taken.<br>• Unavailability of the Workers,<br>• The demand and supply behaviour of the products.<br>• Unavailability of food security<br>• Supply of high content food to workers. |
| KIEL et al. (2017) | Fourth Revolution of Industrialization's Benefits and Challenges for Sustainable Industrial Goals. | Questionnaire based approach | • Knowledge of existing Technology,<br>• Organizational Challenges,<br>• Inconvenience in Data Handling,<br>• Data Insensitivity<br>• Accounting and Costing in Implementation. ,<br>• Human resources, |

Table 2.2: Barriers to implementation of industry 4.0.

| | | Kumar et al. (2020) | Raj et al. (2020) | Kumar et al. (2020) | Rezqianita et al (2020) | Chauhan et al. (2020) | Ozkan-Ozen et al. (2020) | Stentoft et al. (2020) | Horváth et al. (2019) | Stentoft et al. (2019) | Müller (2019) | Türkeş et al. (2019) | Kamble et al. (2018) | Orzes et al. (2018) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Government Policy (GP) | Lack of Govt. initiatives (GP11) | ✓ | | ✓ | | | | | | | | | | ✓ |
| | Policy about data security (GP12) | | | ✓ | ✓ | | | | | | | | ✓ | |
| | Lack of Standards and Reference Architecture (GP13) | | ✓ | ✓ | ✓ | | | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| | Regulatory Compliance issues (GP14) | | | | | | | | | | | | ✓ | |
| | Missing partners and funding support (GP15) | | | ✓ | | | | | | | | | | |
| Management initiatives (MI) | Risk of misinvestment (MI21) | ✓ | | | | | | | | | | | | |
| | Structure/resistance to change (MI22) | | ✓ | | | | | | | | | | | |
| | Lack of waste management strategy (MI23) | ✓ | | | | | | | | | | | | |
| | Lack of management support (MI24) | ✓ | | ✓ | | | ✓ | | | | ✓ | | | ✓ |
| | Lack of knowledge management systems (MI25) | ✓ | | | ✓ | | | | | | | | ✓ | |
| | Lack of planning skills and activities (MI26) | | | | | | | | ✓ | | | | | |
| Human Resources/Workforce (HR) | Lack of trust between Partners (HR31) | | | | | | | | | | | | | ✓ |
| | Lack of Support from Customer/supplier | | | | | | | | | | | | | ✓ |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (HR32) | | | | | | | | | | | | | |
| | Lack of competence from the Workforce/Limited skilled workers (HR33) | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | | |
| | Lack of external experts HR34) | | | | ✓ | | | | | | | | | |
| | Disruption to existing jobs (HR35) | | ✓ | | | | | | | | | | | |
| Infrastructure & Financial Resources (IFR) | Lack of Infrastructure (IFR41) | ✓ | ✓ | | ✓ | | | | | | | | | ✓ |
| | Lack of financial resources (IFR42) | ✓ | | | | | | ✓ | ✓ | ✓ | | | | ✓ |
| | Lack of a digital strategy alongside resource scarcity (IFR43) | | ✓ | | | ✓ | | | | | | | | |
| Technology (T) | Security and Privacy Issues (T51) | | ✓ | ✓ | | | ✓ | | | | | | ✓ | |
| | Seamless integration and compatibility issues (T52) | | | ✓ | | | | | | | | | ✓ | |
| | Very high complexity (T53) | | | ✓ | | | | | | | | | | ✓ |
| | Awareness about the potentialities of robots applications (T54) | | | | | | | | | | | | | ✓ |
| | Challenges in ensuring data Quality (T55) | | ✓ | | | | | | | | | | | |
| | Concerns about cybersecurity and data ownership issues (T56) | | | | ✓ | | | | ✓ | | | | | |

The barriers of industry 4.0 through systematic literature review are summarized in Table 2.2. The reviewed papers highlight a set of 25 barriers in Industry 4.0 implementation that were classified into five criteria:

1. Government Policy (Lack of government initiatives, policy about data security, Lack of Standards and Reference Architecture, Regulatory Compliance issues, and missing partners and funding support).

2. Management Initiatives (risk of misinvestment, structure/resistance to change, lack of waste management strategy, Lack of management support, Lack of knowledge management systems, and Lack of planning skills and activities).

3. Human Resources / Workforce (Lack of trust between partners, Lack of Support from Customer/supplier, lack of competence from the Workforce/Limited skilled workers, lack of external experts, and disruption to existing jobs).

4. Infrastructure & Financial Resources (Lack of Infrastructure, Lack of financial resources, and Lack of a digital strategy alongside resource scarcity).

5. Technology (security and Privacy Issues, seamless integration and compatibility issues, very high complexity, awareness about the potentialities of robots applications, challenges in ensuring data quality, and concerns about cybersecurity and data ownership issues).

### 2.2 Selection of barriers in implementation of Industry 4.0

Based on the opinion and suggestions given by the experts, some major barriers in implementation of Industry 4.0 in SMEs are considered for the analysis as summarized in Table 2.3.

Table 2.3: Selected Barriers to Implementation of Industry 4.0 in the manufacturing industry.

| Barriers | Reference | Remarks |
|---|---|---|
| Lack of Govt. initiatives (GP11) | Kumar et al. (2020),<br>Orzes et al. (2018),<br>Kumar et al. (2020) | the government fails to encourage financial costing, Taxation, Educational training, etc., through Industry 4.0 technologies. |
| Policy about data security (GP12) | Rezqianita et al. (2020),<br>Kumar et al. (2020) | Lack of government initiatives towards the implementation of data loss, privacy loss. |
| Lack of Standards and Reference Architecture(GP13) | Raj et al. (2020),<br>Kumar et al. (2020),<br>Rezqianita et al. (2020),<br>Stentoft et al. (2020), | Designing and selecting an Industry 4.0 architecture for various applications has proven to be a considerable problem, especially |

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| | Stentoft et al. (2019), Türkeș et al. (2019), (Kamble et al. (2018), (Orzes et al., 2018) | when considering the wireless sensory network. |
| Regulatory Compliance issues (GP14) | Kamble et al. (2018) | According to this, the Organization should Adhere to the Rules, Regulations, and Policies Governing to Proper implementation of the fourth Industrial Revolution. |
| Missing partners and funding support (GP15) | Kumar et al. (2020) | Lack of financial inclusion. |
| Risk of misinvestment (MI21) | Kumar et al. (2020) | Deals with the risk involved in the implementation of the fourth industrial revolution. |
| Structure/resistance to change(MI22) | Raj et al. (2020) | Adoptability of the employee in the new industrial environment. |
| Lack of waste management strategy(MI23) | Kumar et al. (2020) | The primary components of circular economy are recycling, reuse, and re-manufacturing. Limited management of waste puts a stumbling block in the way of meeting the circular economy's criteria. |
| Lack of management support(MI24) | Kumar et al. (2020), Ozkan-Ozen et al. (2020), Kumar et al. (2020), Müller (2019), Orzes et al. (2018) | Lack of management support towards the implementation of the fourth industrial revolution on the shop floor |
| Lack of knowledge management systems(MI25) | Kumar et al. (2020), Rezqianita et al. (2020), Kamble et al. (2018) | Limited knowledge towards handling real-time data. Requirement of skilled labour. |
| Lack of planning | Horváth et al. (2019) | Lack of coordination across |

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| skills and activities(MI26) | | organizational units and need to enhance the skill for doing proper planning and activities. |
| Lack of trust between Partners (HR31) | Orzes et al. (2018) | The corporate mentality, having the issue related to the limited cooperation between the departments. |
| Lack of Support from Customer/supplier (HR32) | Orzes et al. (2018) | Limited mutual cooperation, Unskilled labour, and issue related to job security. |
| Lack of competence from the Workforce/Limited skilled workers (HR33) | Kumar et al. (2020), Kumar et al. (2020), Rezqianita et al. (2020), Ozkan-Ozen et al. (2020), Stentoft et al. (2020), Stentoft et al. (2019) | Lack of competence from the workforce due to the lack of knowledge, limited leadership, and technical skill. |
| Lack of external experts (HR34) | Rezqianita et al. (2020) | Improper exposure to the fourth industrial revolution. |
| Disruption to existing jobs (HR35) | Raj et al. (2020) | Employment due to over population required but nowadays machines and new manufacturing technology are replacing the workers. |
| Lack of Infrastructure (IFR41) | Kumar et al. (2020), Raj et al. (2020), Rezqianita et al. (2020), Orzes et al. (2018), | High quality of infrastructure required for successful implementation of industry 4.0. Digital inclusion of technology is needed. |
| Lack of financial resources (IFR42) | Kumar et al. (2020), Stentoft et al. (2020), Horváth et al. (2019), Stentoft et al. (2019), Orzes et al. (2018) | Challenges related to costing and accounting. |
| Lack of a digital | Raj et al. (2020), | Improper supply of required |

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|---|---|---|
| strategy alongside resource scarcity (IFR43) | Chauhan et al. (2020) | resources. Unavailability of proper strategy for digital inclusion of technologies in the implementation of industry 4.0. |
| Security and Privacy Issues (T51) | Raj et al. (2020), Kumar et al. (2020), Ozkan-Ozen et al. (2020), Kamble et al. (2018) | Improper inclusion of communication technologies. Challenges in catering cyber security issues. |
| Seamless integration and compatibility issues (T52) | Kumar et al. (2020), Kamble et al. (2018) | Challenges in implementing the internet of things with physical machines. Inclusion of digital and communication techniques. |
| Very high complexity (T53) | Kumar et al. (2020), Orzes et al. (2018) | The issue is in adopting from the physical world to the cyber-physical world. |
| Awareness about the potentialities of robots applications (T54) | Orzes et al. (2018) | The flexibility of robot application in various manufacturing jobs. |
| Challenges in ensuring data quality (T55) | Raj et al. (2020) | Data Sensitivity and Data Handling. |
| Concerns about cybersecurity and data ownership issues (T56) | Rezqianita et al. (2020), Horváth et al. (2019) | In industry 4.0, cybersecurity and centralized Stored Data and control system are assessment points to measure the readiness of a company adopting Industry 4.0. Proper Communication Inclusion Cater Communication Issues Protection and adhere to Cyber Security Issues. |

**Chapter 3**

# Research Methodology and Case Study

As we know, MCDM methods allow us to consider multiple criteria with different weights. Several MCDM methods are available, but we use a newly developed MCDM method called the best-worst method in this study.

The Best-Worst Method, which helps to determine the significance rating of the barriers on the application of Industry 4.0. It helps in minimising the complexity and effort required for each criterion's pairwise comparison. Only the best (most important) criteria are compared to other criteria, while the worst (least important) criteria are compared to other criteria. Compared to other multi-criteria decision-making techniques like BWM, it provides more accurate findings (Rezaei et al., 2016; Rezaei et al., 2016).

There are the following Mathematical steps to use the BMW method to get the weight of the given criteria:

1. Identify the set of barriers in implementing Industry 4.0in the manufacturing industry through literature review and opinion of the industrial experts.

2. On the basis of the industrial experts, Identify the best barriers (the most significant barriers) and the worst barriers (the least important barriers).

3. On a 9 point rating scale, showing the importance of the best barriers over the other and construct $X_B$ (best-to-other) vector as shown in the equation below

$$X_B = (x_{B1,}\ x_{B2},\ldots\ldots\ldots,x_{Bn}) \qquad (1)$$

Where $x_{BJ}$ indicates the preference of the best B over criterion j. and

$$x_{BB} = 1. \qquad (2)$$

The importance of best barriers over the other barriers sub-grouped in five criteria to implement industry 4.0 (Government policy, Management initiatives, Human Resources/Workforces, Infrastructure & financial resources, and Technology) are mentioned in Tables 3.1–3.6.

These choices were made after consulting with industry professionals. After consulting the industrial experts for ranking different barriers, twelve respondents were selected for taking inputs through the Best-Worst method, and selection of the best or worst factor was best upon each respondent's perception.

Table 3.1: Best over vectors for five criteria in the implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | Government Policy (GP) | Management initiatives (MI) | Human Resources / Workforce (HR) | Infrastructure & Financial Resources (IFR) | Technology (T) |
|---|---|---|---|---|---|---|
| 1 | Technology (T) | 2 | 4 | 8 | 2 | 1 |
| 2 | Technology (T) | 2 | 3 | 7 | 3 | 1 |
| 3 | Technology (T) | 2 | 5 | 8 | 2 | 1 |
| 4 | Infrastructure & Financial Resources (IFR) | 2 | 5 | 9 | 1 | 2 |
| 5 | Infrastructure & Financial Resources (IFR) | 3 | 8 | 5 | 1 | 2 |
| 6 | Government Policy (GP) | 1 | 7 | 6 | 6 | 4 |
| 7 | Human Resources / Workforce (HR) | 2 | 8 | 1 | 4 | 5 |
| 8 | Management initiatives (MI) | 6 | 1 | 3 | 4 | 4 |
| 9 | Management initiatives (MI) | 4 | 1 | 6 | 4 | 3 |
| 10 | Government Policy (GP) | 1 | 8 | 5 | 6 | 4 |
| 11 | Infrastructure & Financial Resources (IFR) | 2 | 4 | 7 | 1 | 2 |
| 12 | Technology (T) | 4 | 2 | 6 | 2 | 1 |

Table 3.2: Best over barriers related to Government policy for implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | GP11 | GP12 | GP13 | GP14 | GP15 |
|---|---|---|---|---|---|---|
| 1 | GP11 | 1 | 4 | 8 | 7 | 5 |
| 2 | GP14 | 3 | 3 | 7 | 1 | 3 |
| 3 | GP11 | 1 | 5 | 8 | 7 | 2 |
| 4 | GP12 | 3 | 1 | 4 | 8 | 4 |
| 5 | GP13 | 3 | 7 | 1 | 3 | 2 |
| 6 | GP11 | 1 | 4 | 8 | 3 | 5 |
| 7 | GP12 | 2 | 1 | 3 | 2 | 4 |
| 8 | GP14 | 2 | 4 | 6 | 1 | 2 |
| 9 | GP11 | 1 | 3 | 8 | 6 | 6 |
| 10 | GP11 | 1 | 4 | 8 | 5 | 3 |
| 11 | GP14 | 5 | 2 | 7 | 1 | 2 |
| 12 | GP11 | 1 | 2 | 8 | 5 | 5 |

Table 3.3: Best over barriers related to Management Initiatives for implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | MI21 | MI22 | MI23 | MI24 | MI25 | MI26 |
|---|---|---|---|---|---|---|---|
| 1 | MI26 | 8 | 7 | 7 | 2 | 3 | 1 |
| 2 | MI25 | 3 | 6 | 8 | 7 | 1 | 4 |
| 3 | MI25 | 5 | 5 | 8 | 6 | 1 | 2 |
| 4 | MI26 | 6 | 8 | 6 | 2 | 3 | 1 |
| 5 | MI25 | 2 | 7 | 8 | 6 | 1 | 3 |
| 6 | MI25 | 3 | 4 | 7 | 5 | 1 | 3 |
| 7 | MI21 | 1 | 3 | 7 | 3 | 3 | 5 |
| 8 | MI21 | 1 | 2 | 5 | 3 | 3 | 4 |
| 9 | MI25 | 4 | 7 | 8 | 5 | 1 | 3 |
| 10 | MI26 | 3 | 8 | 4 | 5 | 2 | 1 |
| 11 | MI25 | 2 | 6 | 7 | 8 | 1 | 2 |
| 12 | MI26 | 2 | 8 | 3 | 2 | 2 | 1 |

Table 3.4: Best over barriers related to Human resources/Workforce for implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | HR31 | HR32 | HR33 | HR34 | HR35 |
|---|---|---|---|---|---|---|
| 1 | HR33 | 8 | 5 | 1 | 6 | 6 |
| 2 | HR32 | 4 | 1 | 4 | 5 | 2 |
| 3 | HR34 | 6 | 8 | 3 | 1 | 7 |
| 4 | HR33 | 7 | 6 | 1 | 3 | 5 |
| 5 | HR34 | 5 | 7 | 3 | 1 | 3 |
| 6 | HR33 | 8 | 7 | 1 | 2 | 4 |
| 7 | HR33 | 8 | 6 | 1 | 3 | 4 |
| 8 | HR35 | 8 | 6 | 2 | 2 | 1 |
| 9 | HR34 | 7 | 7 | 5 | 1 | 8 |
| 10 | HR33 | 8 | 5 | 1 | 6 | 2 |
| 11 | HR35 | 5 | 8 | 2 | 3 | 1 |
| 12 | HR33 | 6 | 4 | 1 | 8 | 3 |

Table 3.5: Best over barriers related to Infrastructure & Financial Resources (IFR)for implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | IFR41 | IFR42 | IFR43 |
|---|---|---|---|---|
| 1 | IFR41 | 1 | 5 | 8 |
| 2 | IFR42 | 2 | 1 | 6 |
| 3 | IFR41 | 1 | 4 | 7 |
| 4 | IFR42 | 2 | 1 | 8 |
| 5 | IFR41 | 1 | 4 | 8 |
| 6 | IFR41 | 1 | 3 | 8 |
| 7 | IFR42 | 3 | 1 | 7 |
| 8 | IFR42 | 4 | 1 | 6 |
| 9 | IFR43 | 2 | 5 | 1 |
| 10 | IFR42 | 5 | 1 | 4 |
| 11 | IFR41 | 1 | 2 | 7 |
| 12 | IFR41 | 1 | 4 | 3 |

Table 3.6. Best over barriers related to technology for implementation of Industry 4.0.

| Respondent No. | Best (Most Important) Impact | T51 | T52 | T53 | T54 | T55 | T56 |
|---|---|---|---|---|---|---|---|
| 1 | T53 | 6 | 7 | 1 | 6 | 6 | 3 |
| 2 | T56 | 4 | 4 | 2 | 8 | 4 | 1 |
| 3 | T56 | 2 | 5 | 3 | 7 | 3 | 1 |
| 4 | T53 | 5 | 6 | 1 | 8 | 5 | 2 |
| 5 | T56 | 3 | 5 | 3 | 7 | 5 | 1 |
| 6 | T51 | 1 | 2 | 4 | 5 | 8 | 4 |
| 7 | T53 | 5 | 7 | 1 | 8 | 7 | 3 |
| 8 | T51 | 1 | 3 | 3 | 7 | 6 | 2 |
| 9 | T51 | 1 | 2 | 2 | 6 | 7 | 3 |
| 10 | T53 | 6 | 7 | 1 | 6 | 6 | 2 |
| 11 | T56 | 4 | 6 | 4 | 8 | 5 | 1 |
| 12 | T54 | 5 | 4 | 3 | 1 | 8 | 5 |

4. To obtain the importance of the criteria j over the worst criteria on a 9-point rating scale and construct $X_W$ (other-to-worst) vector would be:

$$X_W = (x_{1W}, x_{2W},\ldots,x_{nW})^T \qquad (3)$$

where $x_{jW}$ indicates the preference of the criterion j over the worst criterion W. It is clear that

$$x_{WW} = 1.$$

Table No. 3.7-3.12 showing the importance of other barriers over the worst (least important) Barriers in each category.

Table 3.7: Over Worst vectors for five criteria to compare the barriers to implementation of Industry 4.0

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| worst (Least Important) Impact | HR | HR | HR | HR | MI | MI | MI | GP | HR | MI | HR | HR |
| Government Policy:GP | 6 | 5 | 5 | 6 | 2 | 7 | 4 | 1 | 3 | 8 | 5 | 3 |
| Management Initiatives :MI | 3 | 4 | 3 | 4 | 1 | 1 | 1 | 5 | 6 | 1 | 3 | 6 |
| Human Resources / Workforce :HR | 1 | 1 | 1 | 1 | 3 | 2 | 6 | 3 | 1 | 3 | 1 | 1 |
| Infrastructure & Financial Resources: IFR | 5 | 5 | 4 | 8 | 7 | 2 | 2 | 3 | 3 | 3 | 7 | 6 |
| Technology :T | 7 | 8 | 7 | 6 | 5 | 3 | 3 | 2 | 4 | 4 | 6 | 8 |

Table 3.8: Over Worst vectors for government policy (GP) to compare the barriers to implementation of Industry 4.0.

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| worst (Least Important) Impact | GP 13 | GP 13 | GP 13 | GP 14 | GP 12 | GP 13 | GP 15 | GP 13 | GP 13 | GP 13 | GP 13 | GP 13 |
| Lack of Govt. initiatives-GP11 | 7 | 3 | 8 | 4 | 2 | 8 | 4 | 5 | 8 | 8 | 2 | 7 |
| Policy about data security – GP12 | 3 | 4 | 3 | 7 | 1 | 2 | 6 | 3 | 5 | 2 | 5 | 5 |
| Lack of Standards and Reference Architecture – GP13 | 1 | 1 | 1 | 2 | 6 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Regulatory Compliance issues – GP14 | 2 | 8 | 2 | 1 | 2 | 5 | 4 | 7 | 3 | 2 | 8 | 3 |
| Missing partners and funding support – GP15 | 3 | 4 | 6 | 4 | 4 | 2 | 1 | 5 | 3 | 5 | 6 | 2 |

Table 3.9: Over Worst vectors for Management initiatives (MI)to compare the barriers to implementation of Industry 4.0

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Worst (Least Important) Impact | MI 21 | MI 23 | MI 23 | MI 22 | MI 23 | MI 23 | MI 23 | MI 23 | MI 23 | MI 22 | MI 24 | MI 22 |
| Risk of mis investment : MI21 | 1 | 4 | 3 | 3 | 4 | 5 | 8 | 7 | 4 | 5 | 5 | 3 |
| Structure/resistance to change : MI22 | 2 | 2 | 3 | 1 | 2 | 3 | 5 | 5 | 2 | 1 | 4 | 1 |
| Lack of waste management strategy : MI23 | 3 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 3 | 2 |
| Lack of management support : MI24 | 6 | 2 | 2 | 4 | 3 | 2 | 5 | 4 | 3 | 3 | 1 | 4 |
| Lack of knowledge management systems : MI25 | 5 | 7 | 8 | 3 | 6 | 7 | 4 | 3 | 8 | 6 | 8 | 4 |
| Lack of planning skills and activities : MI26 | 8 | 4 | 6 | 7 | 4 | 5 | 3 | 2 | 5 | 8 | 6 | 6 |

Table 3.10: Over Worst vectors for Human Resources / Workforce (HR) to compare the barriers to implementation of Industry 4.0.

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| worst (Least Important) Impact | HR 31 | HR 34 | HR 32 | HR 31 | HR 32 | HR 31 | HR 31 | HR 31 | HR 35 | HR 31 | HR 32 | HR 34 |
| Lack of trust between partners : HR31 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |
| Lack of Support from Customer/ supplier : HR32 | 3 | 6 | 1 | 2 | 1 | 2 | 2 | 3 | 2 | 4 | 1 | 4 |
| Lack of competence from the Workforce/ Limited skilled workers : HR33 | 8 | 2 | 5 | 8 | 4 | 8 | 7 | 6 | 3 | 8 | 6 | 8 |
| Lack of external experts : HR34 | 2 | 1 | 8 | 4 | 7 | 6 | 4 | 6 | 7 | 2 | 4 | 1 |
| Disruption to existing jobs : HR35 | 2 | 4 | 2 | 2 | 5 | 4 | 3 | 8 | 1 | 6 | 8 | 5 |

Table 3.11: Over Worst vectors for Infrastructure & Financial Resources (IFR)to compare the barriers to implementation of Industry 4.0

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Worst (Least Important) Impact | IFR 43 | IFR 43 | IFR 43 | IFR 43 | IFR 43 | IFR 43 | IFR 43 | IFR 43 | IFR 42 | IFR 41 | IFR 43 | IFR 42 |
| Lack of infrastructure : IFR 41 | 8 | 2 | 7 | 6 | 8 | 8 | 3 | 2 | 3 | 1 | 7 | 6 |
| Lack of financial resources : IFR 42 | 3 | 6 | 2 | 8 | 3 | 2 | 7 | 6 | 1 | 6 | 4 | 1 |
| Lack of a digital strategy alongside resource scarcity : IFR 43 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 2 | 1 | 2 |

Table 3.12: Over Worst vectors for Technology (T) to compare the barriers to implementation of Industry 4.0

| | Respondents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Worst (Least Important) Impact | T52 | T54 | T54 | T54 | T54 | T55 | T54 | T54 | T55 | T52 | T54 | T55 |
| Security and Privacy Issues : T51 | 3 | 4 | 5 | 3 | 4 | 8 | 3 | 7 | 7 | 2 | 4 | 4 |
| Seamless integration and compatibility issues : T52 | 1 | 3 | 2 | 2 | 2 | 6 | 2 | 4 | 5 | 1 | 2 | 5 |
| Very high complexity : T53 | 7 | 6 | 3 | 8 | 4 | 3 | 8 | 4 | 5 | 7 | 4 | 6 |
| Awareness about the potentialities of robots applications : T54 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 8 |
| Challenges in ensuring data quality : T55 | 3 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | 1 | 3 | 3 | 1 |
| Concerns about cybersecurity and data ownership issues : T56 | 5 | 8 | 7 | 6 | 7 | 3 | 5 | 6 | 3 | 5 | 8 | 3 |

5. Find the optimal weights of each barrier, divided into five criteria ($w_1^*$, $w_2^*$,…., $w_n^*$).

The main aim is to determine the optimal weights of the different barriers, such that the maximum absolute differences $\left|\frac{W_B}{W_j} - x_{Bj}\right|$ and $\left|\frac{W_j}{W_W} - x_{jW}\right|$ for all j is minimised, which may be translated to the following minimax model:

$$\min_{j} \max \quad \left\{ \left| \frac{W_B}{W_j} - x_{Bj} \right|, \left| \frac{W_j}{W_W} - x_{jW} \right| \right\} \tag{4}$$

Subject to Wj ≥ 0, for all j

The model written above may be represented in the following form

min ξ

Subject to

$$\left| \frac{W_B}{W_j} - x_{Bj} \right| \leq \xi, \text{ for all j} \tag{5}$$

$$\left| \frac{W_j}{W_W} - x_{jW} \right| \leq \xi, \text{ for all j} \tag{6}$$

$$\sum_j Wj = 1 \tag{7}$$

Wj ≥ 0, for all j.

$W_1^*$, $W_2^*$, . . . , $W_n^*$ (optimal weights) and $\xi^*$ are obtained by solving the LP model as shown above) and using the consistency index (CI) as given in Table 3.13 (Rezaei 2016).

The consistency ratio can be obtained using $\xi^*$ and the corresponding CI as given below

$$CR = \xi^*/CI \tag{8}$$

CR ≅ 0 is considered higher consistency; however, no threshold value for the CR in BWM is mentioned (Rezaei 2016; 2016) (Table 3.13).

Table 3.13: The consistency indices for the BWM.

| $X_{BW}$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Consistency Index | 0.00 | 0.44 | 1.00 | 1.63 | 2.30 | 3.00 | 3.73 | 4.47 | 5.23 |

The weights of all the different barriers as per the calculation are shown in Tables 3.14–3.19.

Table 3.14: Optimal Weights of the five criteria for implementation of industry 4.0

| Respondent No. | Government policy (GP) | Management initiatives (MI) | Human Resources / Workforce (HR) | Infrastructure & Financial Resources (IFR) | Technology (T) | Ksi* | CR |
|---|---|---|---|---|---|---|---|
| 1 | 0.225 | 0.112 | 0.047 | 0.225 | 0.391 | 0.059 | 0.026 |
| 2 | 0.237 | 0.158 | 0.047 | 0.158 | 0.400 | 0.074 | 0.032 |
| 3 | 0.229 | 0.092 | 0.049 | 0.229 | 0.401 | 0.056 | 0.024 |
| 4 | 0.234 | 0.094 | 0.041 | 0.398 | 0.234 | 0.070 | 0.031 |
| 5 | 0.165 | 0.053 | 0.099 | 0.435 | 0.248 | 0.061 | 0.027 |
| 6 | 0.564 | 0.072 | 0.104 | 0.104 | 0.156 | 0.060 | 0.026 |
| 7 | 0.261 | 0.061 | 0.443 | 0.130 | 0.104 | 0.078 | 0.034 |
| 8 | 0.075 | 0.464 | 0.184 | 0.138 | 0.138 | 0.088 | 0.038 |
| 9 | 0.138 | 0.474 | 0.066 | 0.138 | 0.184 | 0.079 | 0.034 |
| 10 | 0.552 | 0.059 | 0.126 | 0.105 | 0.158 | 0.079 | 0.034 |
| 11 | 0.225 | 0.112 | 0.047 | 0.391 | 0.225 | 0.059 | 0.026 |
| 12 | 0.114 | 0.228 | 0.051 | 0.228 | 0.380 | 0.076 | 0.033 |
| **Average** | **0.252** | **0.165** | **0.109** | **0.223** | **0.252** | **0.070** | **0.030** |

Table 3.15: Optimal Weights of the barriers related to government policy (GP) for implementation of industry 4.0

| Respondent No. | Lack of Govt. initiatives GP11 | Policy about data security GP12 | Lack of Standards and Reference Architecture GP13 | Regulatory Compliance issues GP14 | Missing partners and funding support GP15 | Ksi* | CR |
|---|---|---|---|---|---|---|---|
| 1 | 0.556 | 0.158 | 0.068 | 0.091 | 0.127 | 0.078 | 0.034 |
| 2 | 0.167 | 0.167 | 0.056 | 0.444 | 0.167 | 0.056 | 0.024 |
| 3 | 0.488 | 0.109 | 0.054 | 0.078 | 0.271 | 0.054 | 0.024 |
| 4 | 0.187 | 0.477 | 0.140 | 0.056 | 0.140 | 0.084 | 0.037 |
| 5 | 0.149 | 0.064 | 0.415 | 0.149 | 0.223 | 0.032 | 0.014 |
| 6 | 0.498 | 0.143 | 0.053 | 0.191 | 0.115 | 0.074 | 0.032 |
| 7 | 0.214 | 0.357 | 0.143 | 0.214 | 0.071 | 0.071 | 0.031 |
| 8 | 0.222 | 0.111 | 0.056 | 0.389 | 0.222 | 0.056 | 0.024 |
| 9 | 0.534 | 0.205 | 0.057 | 0.102 | 0.102 | 0.080 | 0.035 |
| 10 | 0.498 | 0.143 | 0.053 | 0.115 | 0.191 | 0.074 | 0.032 |
| 11 | 0.092 | 0.230 | 0.048 | 0.400 | 0.230 | 0.061 | 0.026 |
| 12 | 0.465 | 0.265 | 0.057 | 0.106 | 0.106 | 0.065 | 0.028 |
| **Average** | **0.339** | **0.202** | **0.100** | **0.195** | **0.164** | **0.065** | **0.028** |

Table 3.16: Optimal Weights of the barriers related to Management initiatives (MI)for implementation of Industry 4.0

| Respondent No. | Risk of mis investment: MI21 | Structure/resistance to change: MI22 | Lack of waste management strategy: MI23 | Lack of management support: MI24 | Lack of knowledge management systems: MI25 | Lack of planning skills and activities: MI26 | Ksi* | CR |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.044 | 0.069 | 0.069 | 0.241 | 0.160 | 0.417 | 0.064 | 0.021 |
| 2 | 0.181 | 0.090 | 0.054 | 0.078 | 0.461 | 0.136 | 0.081 | 0.027 |
| 3 | 0.097 | 0.097 | 0.048 | 0.081 | 0.435 | 0.242 | 0.048 | 0.016 |
| 4 | 0.078 | 0.048 | 0.078 | 0.235 | 0.157 | 0.404 | 0.066 | 0.022 |
| 5 | 0.240 | 0.068 | 0.053 | 0.080 | 0.399 | 0.160 | 0.080 | 0.027 |
| 6 | 0.162 | 0.121 | 0.048 | 0.097 | 0.410 | 0.162 | 0.076 | 0.025 |
| 7 | 0.394 | 0.156 | 0.046 | 0.156 | 0.156 | 0.093 | 0.073 | 0.024 |
| 8 | 0.347 | 0.211 | 0.054 | 0.141 | 0.141 | 0.106 | 0.076 | 0.025 |
| 9 | 0.132 | 0.076 | 0.049 | 0.106 | 0.461 | 0.176 | 0.069 | 0.023 |
| 10 | 0.148 | 0.041 | 0.111 | 0.089 | 0.223 | 0.387 | 0.058 | 0.019 |
| 11 | 0.225 | 0.075 | 0.064 | 0.037 | 0.374 | 0.225 | 0.075 | 0.025 |
| 12 | 0.176 | 0.044 | 0.118 | 0.176 | 0.176 | 0.309 | 0.044 | 0.015 |
| **Average** | **0.185** | **0.091** | **0.066** | **0.126** | **0.296** | **0.235** | **0.068** | **0.023** |

Table 3.17 Optimal Weights of the barriers related to Human Resources / Workforce (HR) for implementation of Industry 4.0

| Respondent No. | Lack of trust between partners HR31 | Lack of Support from Customer/supplier HR32 | Lack of competence from the Workforce/Limited skilled workers HR33 | Lack of external experts HR34 | Disruption to existing jobs HR35 | Ksi* | CR |
|---|---|---|---|---|---|---|---|
| 1 | 0.065 | 0.130 | 0.587 | 0.109 | 0.109 | 0.065 | 0.028 |
| 2 | 0.123 | 0.434 | 0.123 | 0.075 | 0.245 | 0.057 | 0.025 |
| 3 | 0.104 | 0.058 | 0.208 | 0.542 | 0.089 | 0.081 | 0.035 |
| 4 | 0.065 | 0.098 | 0.523 | 0.196 | 0.118 | 0.065 | 0.028 |
| 5 | 0.111 | 0.054 | 0.184 | 0.466 | 0.184 | 0.087 | 0.038 |
| 6 | 0.050 | 0.077 | 0.470 | 0.269 | 0.134 | 0.067 | 0.029 |
| 7 | 0.063 | 0.095 | 0.508 | 0.190 | 0.143 | 0.063 | 0.028 |
| 8 | 0.044 | 0.078 | 0.233 | 0.233 | 0.411 | 0.056 | 0.024 |
| 9 | 0.097 | 0.097 | 0.136 | 0.596 | 0.073 | 0.084 | 0.036 |
| 10 | 0.048 | 0.111 | 0.471 | 0.092 | 0.277 | 0.083 | 0.036 |
| 11 | 0.098 | 0.049 | 0.246 | 0.164 | 0.443 | 0.049 | 0.021 |
| 12 | 0.097 | 0.146 | 0.508 | 0.054 | 0.195 | 0.076 | 0.033 |
| **Average** | **0.081** | **0.119** | **0.350** | **0.249** | **0.202** | **0.069** | **0.030** |

Table 3.18 Optimal weights of the barriers related to Infrastructure & Financial Resources (IFR) for implementation of Industry 4.0

| Respondent No. | Lack of Infrastructure IFR41 | lack of financial resources IFR42 | Lack of a digital strategy alongside resource scarcity IFR43 | Ksi* | CR |
|---|---|---|---|---|---|
| 1 | 0.750 | 0.167 | 0.083 | 0.083 | 0.083 |
| 2 | 0.278 | 0.611 | 0.111 | 0.056 | 0.056 |
| 3 | 0.717 | 0.183 | 0.100 | 0.017 | 0.017 |
| 4 | 0.333 | 0.600 | 0.067 | 0.067 | 0.067 |
| 5 | 0.722 | 0.194 | 0.083 | 0.056 | 0.056 |
| 6 | 0.691 | 0.218 | 0.091 | 0.036 | 0.036 |
| 7 | 0.236 | 0.673 | 0.091 | 0.036 | 0.036 |
| 8 | 0.185 | 0.704 | 0.111 | 0.037 | 0.037 |
| 9 | 0.316 | 0.105 | 0.579 | 0.053 | 0.053 |
| 10 | 0.125 | 0.688 | 0.188 | 0.063 | 0.063 |
| 11 | 0.604 | 0.313 | 0.083 | 0.021 | 0.021 |
| 12 | 0.628 | 0.140 | 0.233 | 0.070 | 0.070 |
| **Average** | **0.465** | **0.383** | **0.152** | **0.049** | **0.049** |

Table 3.19: Optimal Weights of the barriers related to Technology (T) for implementation of Industry 4.0

| Respondent No. | Security and Privacy Issues T51 | Seamless integration and compatibility issues T52 | Very high complexity T53 | Awareness about the potentialities of robots applications T54 | Challenges in ensuring data quality T55 | Concerns about cybersecurity and data ownership issues T56 | Ksi* | CR |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.094 | 0.055 | 0.475 | 0.094 | 0.094 | 0.188 | 0.088 | 0.029 |
| 2 | 0.113 | 0.113 | 0.225 | 0.042 | 0.113 | 0.394 | 0.056 | 0.019 |
| 3 | 0.210 | 0.084 | 0.140 | 0.049 | 0.136 | 0.382 | 0.037 | 0.012 |
| 4 | 0.097 | 0.081 | 0.435 | 0.048 | 0.097 | 0.242 | 0.048 | 0.016 |
| 5 | 0.161 | 0.097 | 0.161 | 0.054 | 0.097 | 0.430 | 0.054 | 0.018 |
| 6 | 0.409 | 0.227 | 0.114 | 0.091 | 0.045 | 0.114 | 0.045 | 0.015 |
| 7 | 0.112 | 0.080 | 0.488 | 0.052 | 0.080 | 0.187 | 0.073 | 0.024 |
| 8 | 0.376 | 0.144 | 0.144 | 0.046 | 0.072 | 0.217 | 0.057 | 0.019 |
| 9 | 0.360 | 0.198 | 0.198 | 0.066 | 0.047 | 0.132 | 0.035 | 0.012 |
| 10 | 0.085 | 0.052 | 0.438 | 0.085 | 0.085 | 0.255 | 0.072 | 0.024 |
| 11 | 0.136 | 0.091 | 0.136 | 0.051 | 0.109 | 0.477 | 0.068 | 0.023 |
| 12 | 0.105 | 0.132 | 0.175 | 0.439 | 0.044 | 0.105 | 0.088 | 0.029 |
| **Average Value** | **0.188** | **0.113** | **0.261** | **0.093** | **0.085** | **0.260** | **0.060** | **0.020** |

Table 3.20: Local and Global Ranking of the barriers to implementation of Industry 4.0

| Barriers of Industry 4.0 | Weight | Effects of Barriers on Industry 4.0 | Local Weight | Local Ranking | Global Weight | Global Ranking |
|---|---|---|---|---|---|---|
| Government Policy (GP) | 0.252 | Lack of Govt. initiatives (GP11) | 0.339 | 1 | 0.085 | 3 |
| | | Policy about data security (GP12) | 0.202 | 2 | 0.051 | 6 |
| | | Lack of Standards and Reference Architecture (GP13) | 0.100 | 5 | 0.025 | 17 |
| | | Regulatory Compliance issues (GP14) | 0.195 | 3 | 0.049 | 7 |
| | | Missing partners and funding support (GP15) | 0.164 | 4 | 0.041 | 10 |
| Management initiatives (MI) | 0.165 | Risk of mis investment (MI21) | 0.185 | 3 | 0.031 | 14 |
| | | Structure/resistance to change (MI22) | 0.091 | 5 | 0.015 | 22 |
| | | Lack of waste management strategy (MI23) | 0.066 | 6 | 0.011 | 24 |
| | | Lack of management support (MI24) | 0.126 | 4 | 0.021 | 21 |
| | | Lack of knowledge management systems (MI25) | 0.296 | 1 | 0.049 | 8 |
| | | Lack of planning skills and activities (MI26) | 0.235 | 2 | 0.039 | 11 |
| Human Resources / Workforce (HR) | 0.109 | Lack of trust between partners (HR31) | 0.081 | 5 | 0.009 | 25 |
| | | Lack of Support from Customer/supplier (HR32) | 0.119 | 4 | 0.013 | 23 |
| | | Lack of competence from the Workforce/Limited skilled workers (HR33) | 0.350 | 1 | 0.038 | 12 |
| | | Lack of external experts (HR34) | 0.249 | 2 | 0.027 | 16 |
| | | Disruption to existing jobs (HR35) | 0.202 | 3 | 0.022 | 19 |
| Infrastructure & Financial Resources (IFR) | 0.223 | Lack of infrastructure (IFR41) | 0.465 | 1 | 0.104 | 1 |
| | | Lack of financial resources (IFR42) | 0.383 | 2 | 0.085 | 2 |
| | | Lack of a digital strategy alongside resource scarcity (IFR43) | 0.152 | 3 | 0.034 | 13 |
| Technology (T) | 0.252 | Security and Privacy Issues (T51) | 0.188 | 3 | 0.047 | 9 |
| | | Seamless integration and compatibility issues (T52) | 0.113 | 4 | 0.028 | 15 |
| | | Very high complexity (T53) | 0.261 | 1 | 0.066 | 4 |
| | | Awareness about the potentialities of robots applications (T54) | 0.093 | 5 | 0.023 | 18 |
| | | Challenges in ensuring data quality (T55) | 0.085 | 6 | 0.021 | 20 |
| | | Concerns about cybersecurity and data ownership issues (T56) | 0.260 | 2 | 0.065 | 5 |

**Chapter 4**

# Result, Discussion, and Conclusion

In this chapter, the result obtained is discussed with the conclusion obtained from the study. The ranking of the different barriers are shown in Table 3.20. The priority of the different barriers and their applications are discussed in the following paragraphs.

## 4.1 Result and Discussion

The study's analysis is based on the professional opinions of the employee from firms in Delhi NCR, India. A huge number of the small and medium-sized manufacturing industries have set up shop in the Delhi NCR area. All the experts belong from the various manufacturing industries; they deal with Industry 4.0. A team having twelve experts was put together to undertake pair-wise comparisons of different criteria. All the experts were experienced in the industry and had more than ten years' experience regarding Industry 4.0

With the help of the application of the BWM method, we obtained a global and local ranking of shortlisted barriers. The global and local ranking of the barriers of industry 4.0 is given in Table 3.20. Because of the highest global weight, it has been observed that lack of infrastructure is the most critical barrier in implementing industry 4.0 as per the Best-Worst method calculation. Due to the unavailability of high-quality infrastructures such as smart mobility, smart logistics, and digital technology, it becomes tough to implement industry 4.0 in the manufacturing industry.

Even though digitalization obtains several financial benefits, the adoption of Industry 4.0 technologies also requires significant financial support. The company needs to invest in transforming the production system into Industry 4.0. Investment is not only for the short term but should be an organized and monitored long-term investment plan. Lack of financial resources is the second most important barrier to implement industry 4.0, as shown in Table 3.20.

The third important barrier is the lack of government initiative.  The government is working proactively to create an ecosystem for the adoption of Industry 4.0. The fourth important barrier is very high complexity. Smart Factory has several novel characteristics, which enables companies to cope with complexity and unexpected disruptions and manufacture products more efficiently.

The fifth important barrier is concern about cybersecurity and data ownership issues. Cybersecurity and centralized data storage and control system are assessment points to measure a company's readiness to adopt Industry 4.0. Because of the increased connection and usage of standard communications protocols that come with Industry 4.0, there is a greater need to secure key industrial systems from cybersecurity attacks. Government programs as one of the main highlighted policies which describe data security in the manufacturing industry by the adoption of industry 4.0. It is found as the sixth significant barrier. Regulatory compliance issue is the seventh significant barrier. Regulatory compliance refers to an organization's objective of being aware of and following all applicable laws, policies, and regulations.

Knowledge management systems that store and retrieve knowledge, discover knowledge sources, capture and use knowledge, improve collaboration, mine repositories for hidden knowledge, and enhance the knowledge management process are examples of information technology systems. So lack of knowledge management system having the eight ranks as shown in Table 30. The ninth significant barrier is security and privacy issues. Organizations face substantial cybersecurity threats linked to verification, authorization, privacy, and access to systems, applications, networks, and data. Due to the unavailability of financial institutions and investment partners, it is hard to implement industry 4.0 technology in the manufacturing industry (tenth). Lack of planning skills and activities having the eleventh rank as shown in Table 3.20. Proper planning and skill are required to manage the resources and various activities towards implementing industry 4.0. Similarly, the ranking of all the other barriers in the implementation of industry 4.0 in the manufacturing industry are determined.

## 4.2 Conclusion

In this study, in-depth literature review was conducted to collect information regarding the different barriers in the implementation of Industry 4.0 in the manufacturing industry (SMEs). A questionnaire survey was conducted (online) to know the opinion of the respondents regarding the importance of the barriers. These barriers were rated on a 9-point rating scale, and the Best-Worst method was used for finding the local and global weightage of different barriers. It is observed that the most important barrier is the lack of infrastructure for proper implementation of the technologies concerned with Industry 4.0. With infrastructure, financial support becomes the second most important barrier. The third important barrier is the lack of government initiatives regarding the development of infrastructure, and financial support was observed. In addition, the implementation of the different kinds of technologies becomes very complex for SMEs. Therefore, the high level of complicity in the data management and implementation of the Industry 4.0 was observed as the fourth important barrier. The fifth important barrier in the handling of big data, the cyber security and data ownership issue, was observed.

This study may help the management to remove the hurdles/barriers in the implementation of Industry 4.0 and improve the digitalization of the processes to minimize the cost of production with improved performance and effectiveness.

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